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The Fabrication of Deuterium Loaded Fiber Bragg Grating and Its Spectral Characteristics in Thermal Annealing

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ABSTRACT

Previous results showed that the non-reversible(hysteresis loop) of Bragg wave length shifting in thermal cycling of the Fiber Bragg Grating which is a high germanium doped optical fiber and high pressure hydrogen loaded was due to the diffusion out of the H₂ residue in thermal annealing. In addition, the O-H absorption peak (1.38 μ m) causes signal attenuation and stability problem in FBG applications. We demonstrated the fabrication of the D₂ loaded FBG with high stability of Bragg wave length in thermal annealing at temperature up to 250 °C. The spectrum characteristics of the D₂ loaded FBG compare to the H₂ loaded FBG is presented. In general, $\Delta \lambda_B$ of the D₂ loaded FBG is narrower than H₂ loaded, and λ_B of the D₂ loaded FBG is more stable than H₂ loaded in thermal annealing. A model base on the UV photo-induced index change in FBG core with D₂ and H₂ loaded to explain the spectrum characteristics between D₂ and H₂ loaded FBG is discussed.

Keywords: Fiber Bragg grating, deuterium loading

1.INTRODUCTION

Fiber Bragg grating has known to be the most advanced passive component for applications in fiber optic communication and sensor systems because of its low insertion loss, narrow band pass, and the flexibility of manipulating desired spectral characteristics [1-5]. FBG can be easily tailored by induced index change, grating length, chirping, and apodization, so that the desired spectral characteristics, such as filtering wavelength, reflectivity, and band-width can be achieved. In general, a FBG device is used to convert the variation of temperature or strain of the tested environment. The Bragg wavelength shifting then can be measured by interrogating, or by interferometric approach [6-9].

Thus, the performance of the fiber-optic sensing system is significantly affected by the spectrum stability of the FBG components.

Various approaches to fabricate the FBG have been demonstrated [10-19]. High pressure H₂ loading is one of the well known process to enhance the photo-sensitivity of the high germanium doped fiber by deep UV writing (248 nm). The hydrogen loading process is low cost and reproducible. Previous report showed that the hydrogen loaded FBG has an intrinsic absorption peak at 1.38 μ m by the O-H bond [20-21]. This O-H absorption might cause intrinsic problem to fiber optic communication system where a 1.3 μ m laser source is usually used. In addition, the residue of H₂ cause the drifting of the effective index change of the fiber, which in turn can affect the reflectivity and Bragg wavelength of the FBG. Although, this drift can be eliminated by cycles of post annealing, but will decrease the reflectivity of the FBG. It is suggested that the hysteresis of Bragg wavelength shifting is contribute to the diffusion out of the H₂ residue in thermal annealing.

In this report, we demonstrate the fabrication of the FBG using high pressure D₂ loading, and shows the improvement of the spectral characteristics of the FBG.

2.EXPERIMENTS

Samples of high germanium doped single mode fiber were kept in 1/4 " stainless steel (SS304) tubing pressurized at 1500 psi of H₂/D₂ for days until the saturation was reached. The concentration of H₂ in the fiber can be monitored by the

H₂O absorption peak at 1.24 μm , but the detection of the D₂ related absorption peaks is beyond the spectrum range of the optical spectrum analyzer (HP 70951B) in use. The saturation of the D₂ is estimated by the diffusion coefficient of D₂ which is $1/\sqrt{2}$ to H₂.

Figure 1 shows the FBG deep UV exposure system. A KrF excimer laser at 248 nm is used to induce the index change of the Ge-doped dispersion sifted fiber, a phase mask with 1.0780 μm grating period is used to generate the grating on the fiber core, and the HP 70951B optical spectrum analysis system with a white light out put is used to record the real time transmission of the FBG during UV exposure at 60 mJ/cm² fluence and 5 Hz pulse rate. Figure 2 shows the transmission spectrum with Bragg wavelength at 1.55 nm of the FBG with D₂ and H₂ loaded. It reveals that the absorption peak of O-H (1.38 nm) appearing beside the 1.55 nm of Bragg wavelength, but is avoided in the spectrum of D₂ loaded FBG.

3.RESULTS AND DISCUSSION

Figure 3 shows the transmission spectrum of the D₂ loaded and H₂ loaded FBG. In general, the spectrum of H₂ loaded FBG is wider than the D₂ loaded FBG, and significantly, a side lobe next to the Bragg reflection peak.

In characterizing the FBG spectrum variation in thermal annealing, the FBG sample was annealed on a hot plat which was kept at a set temperature for a period of time to record the spectrum, then repeat the same process at another higher temperature up to 200 °C. Figure 4,5 are the spectrum variation of H₂ / D₂ loaded FBG in thermal annealing. It is clearly shown that the D₂ loaded FBG has better spectrum stability than H₂ loaded FBG. The Bragg reflection spectrum of the D₂ loaded FBG is almost reversible with temperature, but there is a serious hysteresis loop in the spectrum of the H₂ loaded FBG due to thermal annealing.

It is the fact that the residue of the D₂ or H₂ can vary the effective index n_{eff} of the fiber core. It is suggested that the non-reversible spectral histogram of the H₂ loaded FBG in thermal annealing might be due to the over loading of H₂, in which decrease of concentration of H₂ in fiber core can cause significant drifting of the effective index. If this is the case, it might suggest that the non-reversible variation of the H₂ loaded FBG spectrum in thermal annealing could be improved by reducing the concentration of H₂ in the fiber core to some threshold level. Also, the diffusion coefficient of D₂ or H₂ might be another factor to affect the stability of the FBG spectrum in which the diffusion of D₂ is slower because of its heavier molecular weight, and refers that spectral stability of the D₂ loaded FBG is better than H₂ loaded FBG.

4.CONCLUSIONS

We demonstrated the improvement of the FBG spectral stability by using D₂ loading. The identification of the mechanism responsible for the non-reversible spectrum variation of H₂ loaded FBG in thermal annealing, and the difference of the spectrum characteristics between H₂ loaded and D₂ loaded FBG is not clear. Further experiments to quantitatively measure the variation of the FBG spectrum characteristics parameters in thermal annealing with respect to the concentration of D₂/ H₂ in the fiber core is needed to explore the mechanism of the spectrum variation. Further exploration of the mechanism which responsible to the spectrum characteristics is important to achieve stable FBG devices in practical applications.

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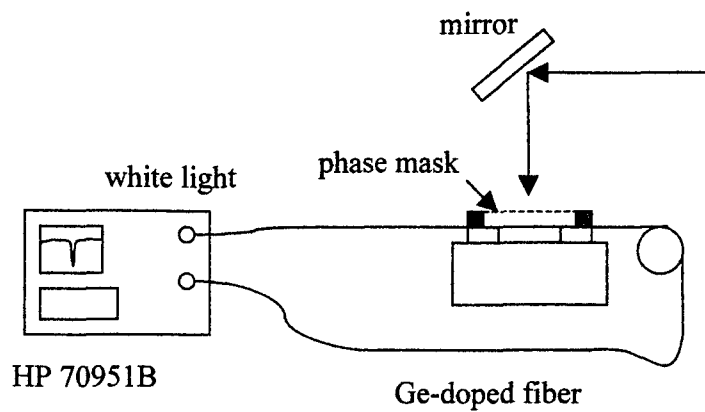
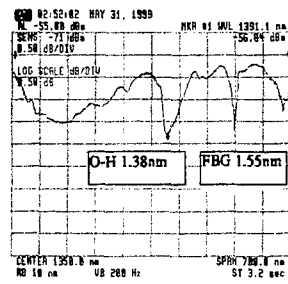
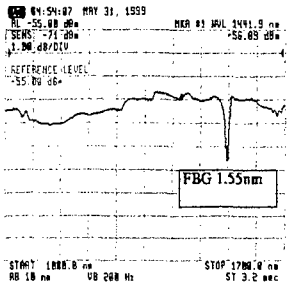


Figure 1. FBG deep UV exposure system. A KrF excimer laser at 248 nm is used to induce the index change of the Ge-doped dispersion sifted fiber, a phase mask with 1.0780 μm grating period is used to generate the grating on the fiber core, and the HP 70951B optical spectrum analysis system with a white light out put is used to record the real time transmission of the FBG during UV exposure at 60 mJ/cm^2 fluence and 5 Hz pulse rate.

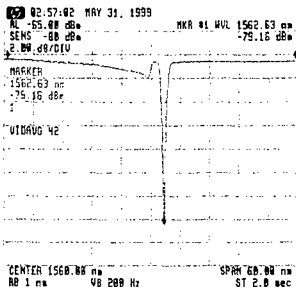


Transmission spectra of the H2 loaded FBG

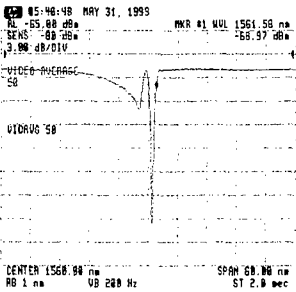


Transmission Spectra of the D2 loaded FBG

Figure 2. The transmission spectrum with Bragg wavelength at 1.55 nm of the FBG with D₂ and H₂ loaded. It reveals that the absorption peak of O-H (1.38 nm) appearing beside the 1.55 nm of Bragg wavelength(upper), but is avoided in the spectrum of D₂ loaded FBG(below).

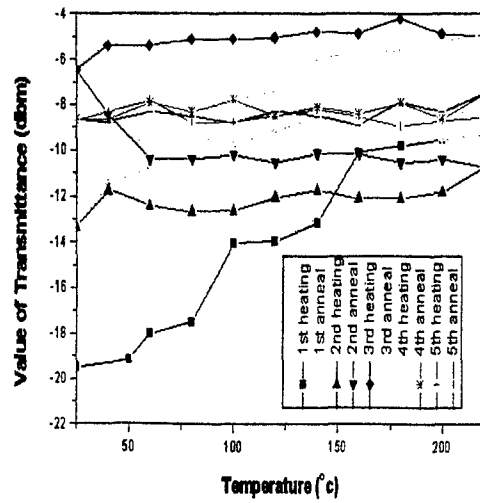


Transmission spectra of the D2 loaded FBG

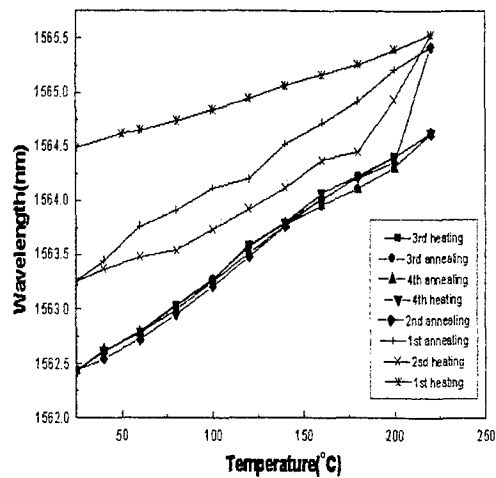


Transmission spectra of the H2 loaded FBG

Figure 3. The transmission spectrum of the D₂ loaded and H₂ loaded FBG. The spectrum of H₂ loaded FBG is wider than the D₂ loaded FBG, and significantly, a side lobe next to the Bragg reflection peak.



Hysteresis of transmission of the H₂ loaded FBG in thermal annealing



Hysteresis of wave length shifting of the H₂ loaded FBG in thermal annealing

Figure 4, The spectrum variation of H₂ loaded FBG in thermal annealing. It is clearly shown that there exists a non-reversible spectrum(hysteresis loop) variation in thermal annealing.

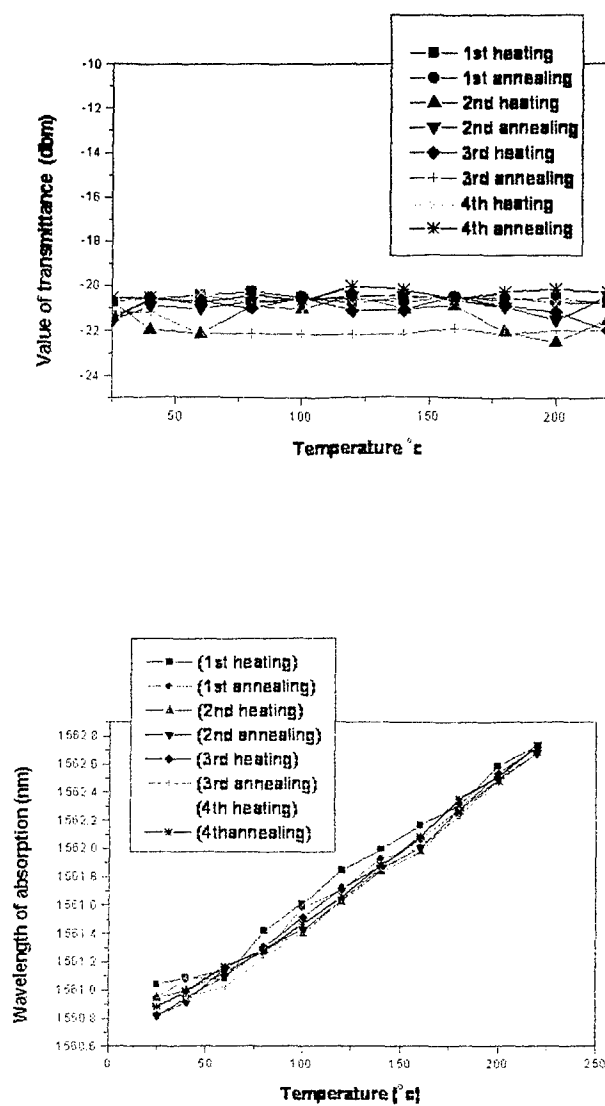


Figure 5. The spectrum variation of D_2 loaded FBG in thermal annealing. It is clearly shown that the D_2 loaded FBG has better spectrum stability than H_2 loaded FBG. The Bragg reflection spectrum of the D_2 loaded FBG is almost reversible in thermal annealing.